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PILOT AIRCRAFT AIMING PERFORMANCE

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FOREWORD

This study was conducted under Project 7194, "Personnel Operations Subsystem for Weapon System 321A," Task 71641, "Human Engineering Aspects of Weapon System 321A." Mr. Donald A. Topmiller was the project engineer, and the author served as task engineer and responsible investigator.

Grateful acknowledgments are extended to Messrs. Donald A. Topmiller and Jean Ring for their many helpful suggestions and to Col. Royal N. Baker and his staff at AFFTC for their cooperation in conducting the test program.

This technical report has been reviewed and is approved.

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ABSTRACT

Six test pilots, using a specially instrumented F-100D, flew nine dives each at a ground target. The task was to align the aircraft with the target as quickly as possible. Initial altitude (7,000, 8,000, or 9,000 feet), dive angle (10°, 20° or 30°), slant range at alignment (6,035 to 50,869 feet), and individual pilot differences did not affect accuracy of alignment. Turbulence, as judged by the pilots, decreased both accuracy and task time. Mean task performance time was approximately nine seconds and mean accuracy was approximately five minutes visual angle.

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SECTION I

INTRODUCTION

There has been a number of occasions when knowledge of the precision with which a pilot can position an aircraft in reference to a target would have been useful information. Some of the most recent uses for which this type of information would be particularly applicable are for the advanced guidance systems which have been proposed for tactical missiles. Since the missile guidance error is usually known, the following study was conducted to determine how much error was ascribable to the man-machine interface, and thus allow the calculation of total system error.

Since it was uneconomical to experimentally test all of the many variables associated with the problem, the more important of these were chosen. Thus this study contains measures of the effects of inter- and intra-pilot variation, altitude, dive angle, slant range, task performance time and turbulence. Training was not of major interest here, and the subjects utilized were highly trained test pilots. One of the more important variables which received no treatment was that of target visibility. Decreased target visibility would be expected to affect performance of the experimental task used, but investigating that parameter lay beyond the scope of this study.

SECTION II

METHOD

Design

This study was conducted as a 6 x 3 x 3 factorial design in which the subjects, dive angles and initial altitudes were the respective variables. Fuel management considerations caused deviations from a counterbalancing procedure for the succession of treatments. Therefore, the altitudes were flown in an ascending or descending series of 2.134, 2.439 and 2.743 km (7,000, 8,000 and 9,000 feet). Similarly, the dive angles were flown in a repetitive 10°, 20° and 30° series. When a position fix was missed or the recording film was poor, the missed trial was made up at the end of the day's runs or on a subsequent flight. This tended to make the succession of the treatments somewhat haphazard.

Subjects

The subjects were six flight test pilots on assignment to the Air Force Flight Test Center. Each had greater than 1,000 hours in high performance jet aircraft of type flown.

Equipment

The test aircraft was a F-100D equipped with an A-4 gunsight which was collimated with a gun camera. The camera was operated by the second detent of the

gun switch. Accelerometers which were to record turbulence levels during the flights were also mounted in the aircraft, but failed to give usable data.

Procedure

All flight tests were conducted at Edwards Air Force Base, California. The subjects were instructed in the flight profiles and briefed on the general purposes of the study. During flights the pilots were given positioning instructions by the radar tracking station which placed them in the appropriate starting position for a dive at the target. The target consisted of five junk sedan cars arranged in a pattern so that one car was in each of four corners a. one in the center of a square with a 25 foot diagonal. When given the go-ahead, the pilot was to enter into one of the various zero bank angle dives, align the aircraft so that the target appeared under the crosshairs of the gunsight, squeeze the gun switch through the second detent, and pull out of the dive. As the trigger was squeezed, the pilot was to notify the radar tracking station and a fix (range and dive angle) was taken of his position relative to the target. The fix plus the error of alignment taken from the gun camera film served as the measures of performance. The pilots were then to mark their mission cards with judgments (heavy, medium, light, or none) of the amount of turbulence they experienced during the dive and then fly around for the next dive. The subjects were instructed that accuracy was the most important part of the task but that speed was also desired. The nature of the task was such to encourage rapid performance of aircraft alignment to avoid hitting the ground, but it is doubted that this had a deleterious effect. All tests were conducted with the aircraft flying speeds as close to mach 0.95 as the pilots could maintain.

SECTION III

RESULTS AND DISCUSSION

The dives were made from the designated altitudes, but there were some deviations from the planned dive angles. Of the 54 dives made, 40 of them were made within one degree and 52 were made within three degrees of the designated angle. The other two dives consisted of +4 and -5 degree deviations. For purposes of analysis all performance measures were grouped according to the designated dive angle. Performance was measured in .5 mil increments as deviations from the target to pilot line of sight. They are reported here in minutes of visual angle so they will be comparable to other reported visual tasks. Table I describes the frequency distribution of scores broken down into the directions of deviation. In elevation, 41% of the trials had zero error while the direction of error is split almost evenly between undershoots and overshoots on the remaining 59% of the trials, representing an average error of 2.19 minutes visual angle. In azimuth, however, only 18.5% of the trials resulted in zero error, while 66.7% resulted in left error and only 14.8% in right error, representing a mean of 4.15 minutes visual angular error. The distribution of azimuthal scores indicates two things: (a) there is more variance in azimuthal aiming, and (b), there is a bias towards the left in the azimuthal scores. These two things must be considered separately as they undoubtedly stem from different sources.

It is not easy to account for the bias present in the scores since an adequate account should require that the airplane be checked. The equipments utilized were removed from the aircraft and the aircraft was assigned to another flight test before the bias was discovered and so a checkout was not performed. In discussions with F-100 pilots about the bias in the scores, all factors but misalignment of the camera with the gunsight were discounted in the absence of further information about the particular aircraft used. On the possibility that the error pattern was due to faulty collimation of the camera and gunsight the data are analyzed both with and without a one mil right azimuth correction. This correction was chosen to render the mean of the distribution of the errors equal to zero. The corrected distribution represents an average error of 3.53 minutes visual angle.

The greater variance in error scores in the azimuth direction as compared with the elevation direction is due to the aerodynamic control of the aircraft which makes course corrections more difficult to achieve than pitch corrections.

TABLE I

FREQUENCY DISTRIBUTION OF ERROR DIRECTION BY PILOTS*

Pilot No.	Azimuth			Elevation		
	Zero	Left	Right	Zero	Over	Under
1	5(6)	3(3)	1(0)	4	2	3
2	1(4)	6(3)	2(2)	6	1	2
3	1(4)	6(3)	2(2)	1	5	3
4	2(4)	6(5)	1(0)	5	2	2
5	1(3)	8(2)	0(4)	3	2	4
6	0(5)	7(2)	2(2)	3	5	1

*Numbers in parentheses are for the distribution of corrected scores.

The basic data may be found in the appendix. Table II lists the means and standard deviations for each subject computed from the error data. The correlation between the means and standard deviations of the basic data ($\rho = .8286$, $p < .05$) dictates that a variance stabilizing transformation be placed on the data before a variance analysis is performed. The transformation used was the modified square root transform ($\sqrt{x} + \sqrt{x} = 1$) suggested by Freeman and Tukey[1].

[1]Freeman, M. F. and Tukey, J. W. Transformations related to the angular and the square root. Ann. Math. Statist., 1950, 21, 607-611.

TABLE II

MEANS AND STANDARD DEVIATIONS OF PILOT PERFORMANCE
(ENTRIES ARE IN MINUTES OF ANGULAR ERROR)

Pilots	1	2	3	4	5	6
Means	4.22	5.38	7.18	7.28	4.46	5.05
Standard Dev.	2.59	3.83	4.09	4.98	3.02	1.92

The results of the analysis of variance are shown in table III. From the summary it is obvious that neither of the testable main effects (altitude and dive angle) and none of the second order interactions are significant.

TABLE III

ANALYSIS OF VARIANCE ON TRANSFORMED SCORES

Source	df	ss	ms
Altitude (A)	2	1.49	.75
Dive Angle (D)	2	.72	.36
Subjects (S)	5	11.35	2.27
AXD	4	5.16	1.29
AXS	10	36.61	3.66
DXS	10	14.91	1.49
AXDXS	20	64.58	3.23
TOTALS	53	134.82	

Since there is no appropriate error term for testing the subjects main effect, the range determined allowances method of Link and Wallace described by Mosteller and Bush[2] was applied. The results of this analysis can be found in table IV from which it can be seen that no significant pilot differences exist.

[2]Mosteller, F. and Bush, R. R. "Selected Quantitative Techniques in Handbook of Social Psychology." Gardner Lindzey (Ed.). Cambridge: Addison - Wesley, 1954.

TABLE IV

RANGE DETERMINED ALLOWANCES FOR PILOT DIFFERENCES

UNCORRECTED SCORES

	PILOTS					
Altitudes	1	2	3	4	5	6
7000	14.89 (+4.31)	10.58 (-7.73)	18.31 (+6.66)	11.65 (-5.34)	16.99 (+3.14)	13.85 (-1.04)
8000	7.93 (-9.15)	17.08 (+2.53)	14.55 (- .95)	15.50 (+3.96)	11.54 (-1.77)	13.31 (+5.38)
9000	13.80 (+ .81)	12.99 (-2.42)	15.41 (-3.81)	19.22 (+9.33)	9.89 (-4.96)	14.45 (+ .65)
TOTALS	36.62	40.65	48.27	46.37	38.42	41.61
Range of Differences	13.46	10.26	10.47	14.67	8.10	6.42

Sum of Ranges	63.38
Critical Factor	.62
Allowance	39.30

CORRECTED SCORES

	PILOTS					
Altitudes	1	2	3	4	5	6
7000	16.89 (2.92)	13.97 (-11.91)	25.88 (10.41)	15.47 (.64)	14.83 (-2.95)	17.78 (.89)
8000	12.36 (-8.26)	20.62 (5.02)	15.60 (1.74)	13.86 (9.70)	4.16 (-11.87)	16.03 (3.77)
9000	10.94 (3.34)	7.60 (-6.98)	14.58 (-10.98)	25.56 (19.78)	5.78 (-2.54)	8.32 (-2.62)
TOTALS	40.19	42.19	56.06	54.89	24.77	42.13
Range of Differences	11.60	16.93	21.39	19.14	9.33	6.39

Sum of ranges	84.78
Critical Factor	.62
	52.56

The analysis of variance for the corrected and similarly transformed scores is summarized in table IV from which it can be seen that the same conclusions are warranted from it as were drawn from the previous analysis on the uncorrected scores.

TABLE V

ANALYSIS OF VARIANCE FOR CORRECTED SCORES

Source	df	ss	ms
Altitude (A)	2	5.64	2.82
Dive Angle (D)	2	.58	.29
Subjects (S)	5	17.71	3.54
AXD	4	6.07	1.52
AXS	10	13.46	1.34
DXS	10	21.74	2.17
AXDXS	20	52.98	2.65
TOTALS	53	118.18	

Although for a given altitude and dive angle combination each pilot started the dive at approximately the same slant range to the target, the task time varied which in turn varied the slant range sighting. This could have obviated a significant Altitude X Dive Angle interaction, so a Spearman rho was computed for sighting error and slant range at sighting. The correlation coefficient yielded was virtually zero ($\rho = .015$, df = 53).

Since none of the independent variables or their interactions are significant, one can characterize the performance of the task with simple descriptive statistics. The mean error for all subjects under all conditions was 5.59 minutes of angular error; the standard deviation is 3.75 minutes of angular error. For the corrected scores the mean and standard deviation were 4.82 and 3.39, respectively. Task performance time (from pushover to gun camera activation) ranged from 1.6 to 31.2 seconds with a mean of 8.76 seconds and a standard deviation of 1.84 seconds. All subjects were able to perform the task at least once with less than 4' arc error in less than 8.76 seconds with four of the subjects completing the task this quickly with less than 2' arc error.

Although the accelerometers did not yield usable data for measuring the effects of turbulence on performance, pilot judgments were recorded after each trial. Four of the pilots used all of the four rating categories for turbulence: none, light, medium and heavy. Two pilots did not judge any of the trials as being conducted under heavy turbulence. Table VI describes performance under the variously judged trials.

TABLE VI

PERFORMANCE UNDER JUDGED TURBULENCE

	JUDGED TURBULENCE			
	None	Light	Medium	Heavy
No. of trials	10	24	14	6
Range of error scores	0.00 - 3.45	1.72 - 8.59	3.95 - 8.76	6.86 - 17.27
Mean error score	1.62	4.68	6.72	13.24
Mean task time	10.77	8.97	7.69	7.17

An extension of the median test yielded a χ^2 22.08, 3 df, $p < .001$ between the judged conditions. Although the judged turbulence could have been used as a medium to alibi poor performance, discussions with two of the pilots who served as subjects caused the author to conclude that this was not the case.

Table VI also demonstrates the inverse relationship which obtained between judged turbulence and task time. The difference between the turbulence conditions is significant (χ^2 8.27, 3 df, $p < .05$). Since this relationship indicates that the greater the turbulence, the less time a pilot was willing to stay in the dive, the poorer accuracy found in turbulence could be due to the combined factors of mechanical task interference and the induction of reduced task time.

SECTION IV

CONCLUSION

In a high performance aircraft a pilot can perform an aircraft aiming task with a fairly high degree of accuracy. During these tests the task was performed in approximately 9 seconds with an accuracy of approximately 5' visual angle. This reflected an average of 4.15' (3.53' corrected) azimuthal error and 2.19' elevation error. Initial altitude, slant range and dive angle gave no evidence of affecting accuracy. There was no evidence of significant inter-subject differences. Turbulence did affect accuracy, though, with performance approaching laboratory levels of visual acuity in the absence of judged turbulence. Turbulence also affected task time with the higher levels of turbulence resulting in decreased task times. Since greater pilot-aircraft error occurs in the azimuthal direction, greater efforts directed at reducing missile guidance error in this direction are warranted.

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APPENDIX

Pilot No. 1

Run No.	Dive Angle (Degrees)	Initial Altitude (Feet)	Slant Range at Pushover (Feet)	Slant Range at Firing (Feet)	Task Time (Sec)	Sighting Error Min. vis. angle Uncorrected	Sighting Error Min. vis. angle Corrected	Turbulence
1	10	9000	51,900	22,127	27	1.72	4.06	Light
2	18	9000	29,100	11,113	16.2	6.86	3.44	Light
3	29	9000	18,590	9,380	8.8	6.86	3.44	Light
4	10	8000	46,100	10,400	31.2	1.72	4.06	None
5	20	8000	23,400	14,500	7.7	3.45	4.86	Light
6	32	8000	15,100	7,600	6.5	0.00	3.44	None
7	8	7000	50,050	23,400	22.2	6.86	3.44	Moderate
8	22	7000	18,650	6,300	10.2	3.45	4.86	Light
9	29	7000	14,400	6,200	6.8	7.08	8.59	Moderate

Pilot No. 2

1	9	9000	57,800	50,869	6.3	2.44	2.44	None
2	21	9000	25,050	12,850	10.5	3.85	1.72	Lt
3	27	9000	19,900	9,530	9.8	6.86	3.44	Hvy
4	10	8000	46,100	38,745	6.4	14.28	10.31	Hvy
5	20	8000	23,400	15,944	6.5	3.45	0.00	Lt
6	29	8000	16,450	10,792	4.9	6.86	10.31	Mod
7	10	7000	40,400	30,425	8.3	0.00	3.44	None
8	19	7000	21,500	11,043	8.7	3.85	7.09	Lt
9	31	7000	13,600	6,035	6.3	6.86	3.44	Lt

Pilot No. 3

Run No.	Dive Angle (Degrees)	Initial Altitude (Feet)	Slant Range at Pushover (Feet)	Slant Range at Firing (Feet)	Task Time (Sec)	Sighting Error Min. vis. angle Uncorrected	Sighting Error Min. vis. angle Corrected	Turbulence
1	9	9000	57,800	46,100	10.6	7.68	4.86	Mod
2	19	9000	27,700	15,300	11.3	7.68	4.86	Mod
3	27	9000	19,900	6,700	12.0	3.45	4.86	None
4	9	8000	51,000	34,200	14.6	2.44	2.44	Lt
5	22	8000	21,300	15,600	5.0	7.68	9.72	Lt
6	27	8000	17,600	7,600	8.7	6.86	3.44	Lt
7	11	7000	36,700	29,663	6.1	3.85	1.72	Mod
8	19	7000	21,500	9,200	10.2	17.27	17.28	Hvy
9	25	7000	16,580	7,200	7.8	7.68	6.88	Mod

Pilot No. 4

Run No.	Dive Angle (Degrees)	Initial Altitude (Feet)	Slant Range at Pushover (Feet)	Slant Range at Firing (Feet)	Task Time (Sec)	Sighting Error Min. vis. angle Uncorrected	Sighting Error Min. vis. angle Corrected	Turbulence
1	12	9000	43,300	36,424	6.2	6.86	3.44	Mod
2	21	9000	25,050	18,157	6.3	7.68	9.72	Mod
3	34	9000	16,100	7,119	8.1	15.84	12.40	Hvy
4	10	8000	46,100	38,529	6.6	3.45	4.86	Lt
5	20	8000	23,400	21,425	2.0	7.08	3.84	Lt
6	29	8000	16,450	13,523	2.6	8.59	5.16	Lt
7	10	7000	40,400	35,879	3.8	14.28	10.31	Hvy
8	19	7000	21,500	18,230	2.7	1.72	1.72	Lt
9	29	7000	14,400	9,288	4.3	0.00	3.44	None

Pilot No. 5

Run No.	Dive Angle (Degrees)	Initial Altitude (Feet)	Slant Range at Pushover (Feet)	Slant Range at Firing (Feet)	Task Time (Sec)	Sighting Error Min. vis. angle Uncorrected	Sighting Error Min. vis. angle Corrected	Turbulence
1	10	9000	51,900	37,390	14.6	1.72	1.72	None
2	19.5	9000	27,000	16,350	9.7	1.72	4.06	None
3	33	9000	16,580	7,065	8.7	3.45	0.00	Lt
4	11	8000	42,000	36,668	4.6	3.85	1.72	Mod
5	20	8000	23,400	19,885	3.1	3.45	0.00	Lt
6	31	8000	15,580	6,845	7.6	2.44	2.44	Lt
7	10	7000	40,400	38,725	1.6	8.76	5.43	Mod
8	21	7000	19,500	14,915	3.8	3.85	1.72	Mod
9	32	7000	13,200	7,625	4.7	10.91	7.68	Hvy

Pilot No. 6

Run No.	Dive Angle (Degrees)	Initial Altitude (Feet)	Slant Range at Pushover (Feet)	Slant Range at Firing (Feet)	Task Time (Sec)	Sighting Error Min. vis. angle Uncorrected	Sighting Error Min. vis. angle Corrected	Turbulence
1	9	9000	57,800	32,300	23.2	5.45	2.44	Lt
2	19	9000	27,700	17,250	9.5	3.85	2.44	Lt
3	29	9000	18,590	6,990	10.4	6.86	3.44	Lt
4	10	8000	46,100	34,920	9.7	7.68	10.87	Mod
5	20	8000	23,400	17,905	4.8	4.88	3.44	Lt
6	31	8000	15,580	6,980	7.5	1.72	1.72	None
7	11	7000	36,700	28,000	7.3	3.45	6.88	None
8	19	7000	21,500	17,010	3.8	3.85	4.06	Lt
9	33	7000	12,870	6,580	5.2	7.68	6.88	Mod

SUMMARY OF UNCORRECTED MISALIGNMENT SCORES

Altitude	7	7	7	8	8	8	9	9	9	
Dive Angle	10	20	30	10	20	30	10	20	30	Totals
Pilots										
1	6.86	3.45	7.08	1.72	3.45	0.00	1.72	6.86	6.86	38.00
2	0.00	3.85	6.86	14.28	3.45	6.86	2.44	3.85	6.86	48.45
3	3.85	17.27	7.68	2.44	7.68	6.86	7.68	7.68	3.45	64.59
4	14.28	1.72	0.00	3.45	7.08	8.59	6.86	7.68	15.84	65.50
5	8.76	3.85	10.91	3.85	3.45	2.44	1.72	1.72	3.45	40.15
6	3.45	3.85	7.68	7.68	4.88	1.72	5.45	3.85	6.86	45.42
Totals	37.20	33.99	40.21	33.42	29.99	26.47	25.87	31.64	43.32	302.11

Dive Angle	Total Error
10	96.49
20	95.62
30	110.00
	302.11

Altitude	Total Error
7000	111.40
8000	89.88
9000	100.83
	302.11

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13. ABSTRACT

Six test pilots, using a specially instrumented F-100D, flew nine dives each at a ground target. The task was to align the aircraft with the target as quickly as possible. Initial altitude (7,000, 8,000, or 9,000 feet), dive angle (10°, 20°, or 30°), slant range at alignment (6,035 to 50,869 feet), and individual pilot differences did not affect accuracy of alignment. Turbulence, as judged by the pilots, decreased both accuracy and task time. Mean task performance time was approximately nine seconds and mean accuracy was approximately five minutes visual angle.

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13. **ABSTRACT** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

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AMRL-TR-64-87 September 1964

ERRATA - December 1964

The following corrections apply to Technical Report No. AMRL-TR-64-87, Pilot Aircraft Aiming Performance.

Page 3

Change the equation in the third paragraph, 6th line to read:

$$(\sqrt{x} + \sqrt{x + 1})$$

Page 5

On the bottom line of Table IV the figure "52.56" should be preceeded by the word "Allowance."

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